Fluid Flow Visualization in Porous Materials

New Magnetic Resonance Imaging Technique Developed

Alex Pines, in collaboration with scientists at Schlumberger-Doll Research, have developed a new magnetic resonance imaging (MRI) technique that that can be used to observe gas flow through opaque materials such as porous rocks. The new method has possible applications in oil exploration, *in-situ* monitoring of natural and manmade structures, detection of toxic materials and biohazards, and medicine.

Nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI) are analytical tools with unparalleled flexibility and applicability. In a typical "traditional" NMR experiment, a radio frequency (rf) coil is used to disturb the orientation of atomic nuclei in a substance; the same coil is used a moment later to detect the radio waves emitted by these same nuclei, thus providing information about their positions in that substance. In the new approach described here, these steps are spatially separated by using two rf coils. One coil surrounds the porous sample of material and can, in combination with magnetic field gradients, selectively disturb nuclei of fluid flowing through a tiny volume element anywhere in the sample of material. The second coil, positioned where the fluid exits the material, can detect that emerging fluid. In practice, the first coil is used to "tag" certain nuclei at a given point in time, while the second coil is used to record the time of flight of the tagged nuclei as they leave the sample of material. Knowing the location and velocity of small gas volumes, in turn, allows the visualization of fluid flow through the material.

In a first demonstration of this technique, the flow of ^{129}Xe—"hyperpolarized" by a laser to increase its spin polarization—through sandstone of the type found in oil and gas fields was visualized. As shown in the figure, full 3-D visualization of the gas flow through the 20 mm diameter sample of sandstone was achieved. Although the rock had used high overall uniformity, observable deviations of the flow pattern from the expected cylindrical symmetry revealed the locations of small heterogeneities. In a second demonstration, flow through a microfluidic device was measured. This miniaturized "laboratory on a chip" contains small channels through which tiny volumes of fluid flow undergo reactions. Although the channel diameter was only 2 mm, two-dimensional images of gas flow as a function of time were obtained, demonstrating clearly the sensitivity and spatial resolution of the technique in spite of the small sample size. Work is continuing to extend the method to the study of liquid flow in channels with micrometer dimensions.

The new method is flexible in that it allows the experimenters to maximize sensitivity at the expense of time resolution (tens of microseconds to milliseconds) or time at the expense of sensitivity. Extensions of the method to medical diagnostics, as in the study of blood flow through arteries or veins or the real-time monitoring of a patient at low magnetic fields during surgery are envisioned. For the microfluidic application, work is ongoing to integrate low-cost "tagging" and detection electronics onto the chip.

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